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Danish precast 2010- components, joints and project

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Published in:
Noteworthy Developments in Precasting and Prestressing

Publication date:
2010

Document Version
Publisher's PDF, also known as Version of record

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Citation (APA):
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TECHNICAL UNIVERSITY OF DENMARK
DTU Byg – Department of Civil Engineering
Section Building Design

POK/kik/2010

5th International Symposium on:
NOTEWORTHY DEVELOPMENTS IN PRECASTING AND PRESTRESSING
Singapore August 2010

Associate Professor Per Kjærbye
Technical University of Denmark

History of Prefab in Denmark, in short
Shortly after the end of the 2nd world war, there was a great and growing need for housing in Denmark. The main reasons were the many old and partly destroyed town houses, but also people moving from the country side to towns, and also there was a change in family pattern in the sense that youngsters preferred to leave home and live on there own earlier than before.
The politicians as well as the building sector both took up the challenges. The Danish Building Law and Regulations installed clauses which tempted investors, architects, engineers and contractors to develop prefabricated building systems, to built factories in order to produce prefab concrete components with standardized formwork, to invest in transportation and handling devices, such as lorries, cranes, cast-in lifting systems etc.
The National Building Code, June 10. 1960:"*For dwelling houses erected for rental purposes, dimensional standards can normally be adopted which will promote the use of standardized building components, installations and fittings*".
The Danish Building Regulations, August 1966:"*Dwelling houses erected for rental purposes shall be designed in accordance with Danish Modular Standards*".
Rapidly these initiatives resulted in a great production and realization of prefabricated houses. To begin with the industry aimed at only producing open building systems with products covering solid concrete load-bearing walls, sandwich facades and hollow core slabs,- but in a short while more specialized components were developed, such as stairs, landings, columns, beams and frames.
All concrete components were to begin with normally reinforced, but gradually there was a need for longer spans, meaning fewer columns and fewer load-bearing walls, therefore the prestressing techniques were introduced in the prefabrication building programme.

Prefabrication means: focus on joints
Building with prefabricated units calls for design of efficient load-transmitting joints. As prefabricated components are normally simply supported elements, they are easy to design structurally. But, in order to get a prefab-building to act almost as a traditionally cast-on-site structure it is important to create and design structural joints, which must be capable to transmit all calculated forces from one component to another.
In relation to a prefab-building it is therefore even more important to make a detailed description of the entire load path, all the way from load attacking point to foundation and soil. Only on this basis it is possible to make a proper design of structural joints.
Structural joints in the building envelope should be designed on a holistic approach, meaning to take into account all relevant functional requirements.

The keyed shear joint

As an example focus is on the important shear joint between wall elements or slab elements. This joint shall ensure the element structure to act as a cast-on-site structure.

The joint is basically a construction joint type with no shear capacity at all. The Danish designers added some roughness to the wall- and slab-edges, made some tests in the structural laboratory, and came up with: the keyed shear joint.

The bearing capacity for the joint was to begin with simply considered to be 25% of the shear force in the total cross section of the joint,- simply because the active keyed section was only ¼ of the total cross section.

In the Danish Code of Practice for the Structural Use of Concrete in 1973 the shear in construction joints was defined as 0,3 x $f_{tensile}$.

The next many years researchers calculated and tested the bearing capacity of the joint and finally came to a result quit near to the estimated value, done many years earlier by talented structural engineers.

So finally in 1999 the fully developed expression for the bearing capacity for this important joint was installed in the Code:

$$t_{shear} = k_T \times t_{cd} + \mu(\rho \times f_{yd} \times \sin\alpha + \sigma_{nd}) + \rho \times f_{yd} \times \cos\alpha < 0{,}5 \times v_c \times f_{cd}$$

taking into account the joint roughness, the geometry of the keys, the key angle, the concrete strength, the amount of bars, the reinforcement strength, the joint friction, and the compression forces if any. See also enclosure 1.

The slab-wall connection

Very early in the development process of precast systems, the slab-wall connection came into focus. This joint shall transfer both vertical and horizontal forces, and at the same time the bearing for the slabs should be a simply support type and not create a restrained support.

Supporting cams in the bearing line instead of a full line support was invented, allowing all forces in question to go though this joint. This technique is still used for normal reinforced slab and wall components.

Introducing the prestressed slabs to be produced in an extruding process, supporting cams are not possible to make, which leads to a normal line support type. This means a more narrow casting zone between the slabs,- which again means that designers must evaluate carefully the transfer of vertical and horizontal forces through this joint.

The consequences could be splitting forces in the wall components near the joint, meaning that links have to be installed in top and bottom of the walls. See also enclosure 2.

Precast and prestressed component for skeleton building systems

Almost all residential buildings in Denmark are constructed with standardized normal reinforced precast concrete components, such as slabs, walls, facades and gables, stairs and balconies. Whereas office buildings and buildings for industrial purposes are normally structured with prestressed precast components in a skeleton system, using foundation boxes, columns, beams, slabs, and external walls.

Structural joints in skeleton precast building systems

Enclosure 3 and 4 deals with some main assembly details for structural joints often used in skeleton systems in Denmark for office blocks and industry buildings. As mentioned earlier the load path description is of very great importance for the structural design: *macro-static* evaluations for the main structure, and *micro-static* considerations for the structural joints.

Foundation box and column connection:
Vertical forces should be transferred via keyed profiles in box shaft and columns, and further to the box bottom plate and to the ground, whereas horizontal forces will be absorbed in the restraining zone between column and box shaft, and from there further on to box bottom plate, and to the ground.
Column and beam connection:
This connection type is almost always pinned with simply supported beams on column brackets. The joint will normally be secured by dowels, loose or fastened, depending on force transmission in the main structural systems.
If the joint operates with column connection as well, the compression zone between the beams has to be evaluated due to splitting forces in top and bottom of the column.
Beam and slab connection:
To avoid stacking beams and slaps on top of each other, beams are normally of the inverted T-type meaning beams with brackets. Slabs could be the hollow core type or double-T-plates.
The connection should be secured by welding via cast-in steel plates, or by dowels or by joint reinforcement.
Slab and wall connection 1:
In enclosure 3 one of the details deals with an often used assembly method between a load-bearing external wall of the sandwich type, and a double-T-plate.
The support is anchored by cast-in links in the ribs, locking the stringer zone in the wall top as a cast-on-site solution.
Slab and wall connection 2:
The construction detail between a double-T-plate and a non-load-bearing facade is often chosen as a steel angle profile bolted to an anchor rail in the facade and a cast-in device in slab. The connection should enable transfer of horizontal forces and at the same time allowing vertical movements. See the detail on enclosure 4.
Connection detail between slab and wall:
The producer suggests also a welded and bolted connection between a double-T-plate and a non-load-bearing facade,- and the horizontal shear force for the detail is calculated to a design value of 10 kN.
Connection detail between slab and slab:
Also the slab-slab connection is suggested by the producer, f.inst. as welded joint via a loose steel plate to cast-in plates. The design value for shear force is informed to be 15 kN.
Wall-column-wall connection:
The last assembly detail is a horizontal section in the building corner, showing two facade elements connected to the corner column. The joint is secured by a special steel device and afterwards the space between the components is packed with thermal insulation.

Latest developments in precast and prestressed building systems
ThermoMax slab component
In order to meet the increasing demands for energy savings for buildings and for the comfort of the users, one of the greatest prestressed producers in Denmark has developed a thermal active hollow-core slab component, called the TermoMax Slab.
The component is shown at enclosure 5 and is simply cast-in cobber pipes with both in- and outlet at one end of the slab near to the support. Connecting the pipes it is possible to circulate water and thereby remove heat from the room to a storage,- or to supply hot or cold water from the storage, if needed.

The attached diagram shows theoretically in a brief manner how the TermoMax slab works and how it is able to level the indoor thermal condition.

Light beam and column system
The latest development within precast and prestressed building systems is the LB-system, where LB stands for "low beam", meaning a beam with low or thin brackets.
Where the normal inverted-T-beam presented ealier operates with a bracket height at approximately 200 mm, the LB-type introduces a bracket height at only 80 mm.
The LB-beam can act as a simply supported member, or it can be cantilevered as a continuous beam together with a new column-beam connection, and a beam-beam connection as well.
As the beam is not at the moment fully developed, assembly details at enclosure 6 are only preliminary drawings. The LB-system is undergoing structural tests in order to study the micro-statics in the bracket and thereby optimize the reinforcement arrangement.
Fire tests are carried out as well, and preliminary results show that no fire protection is needed.

Project example
NETTO-high store building
Enclosure 7 deals with some project drawings showing an elevation of the main structural system in a one-storey warehouse. Precast columns, prestressed and 16.6 metre high, are connected to foundation boxes in the standardized manner. Simply supported beams on top of the columns support TT-roof plates.
The building is cross braced for wind or mass forces in both directions.

Hotel Copenhagen Island
The entrance building with an area of 15 x 15 metre is a 7-storeys high structure where the first 6 storeys are fully precast. Prestressed columns, 25.4 metre high, are placed in a 3 metre module. At each floor level a beam is installed and temporary supported via keyed shear joints between beams and columns. Afterwards all beams in each façade are posttensioned in order to obtain the horizontal forces and reduce the deflections. The column-beam systems finally act as a multi frame member.
Enclosure 8 shows some component and assembly drawings from the structural engineer.

JYSK-central store building, greatest in Northern Europe
This high bay warehouse for storage has recently been erected in the Danish peninsular Jutland. It consists of three 40 metres high blocks, 135 x 55 m,- two 15 metre high mini-load buildings, each 15.000 sq. metre,- and a distribution hall, service area and administration building in two to four storeys, 70 x 450 m. All together approx. 73.000 sq. metre, with a volume of approx 1.3 mill. cubic metre.
An aerial view on enclosure 9 shows the finished project, prepared for two more high blocks.
The bearing and bracing structure in the high blocks are formed by the clad-rack installation in connection with a light roof and façade system, whereas the distribution building is fully precast using prestressed members which are joint using standard assembly details.
Enclosure 9 and 10 show a few of the main structural joints. Notice, that calculated design values for joint forces are many times repeated on the drawings.

SHEAR IN CONSTRUCTION JOINTS

Extract from:
Danish Code of Practice for the
STRUCTURAL USE ÓG CONCRETE

Old version from 1973:

On the assumption that there are no tensile stresses in construction joints, the concrete may be assumed to resist shear stresses that are at most equal to 30% of the design tensile strength of the concrete, i.e.:

$$t_{shear} = 0{,}3\text{x}\ f_{tensile}$$

New version from 1999:

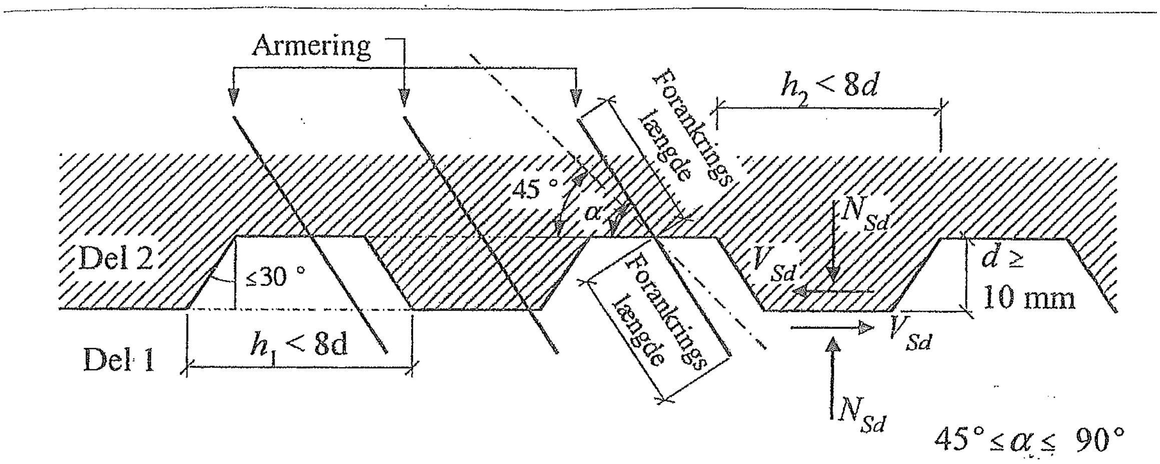
Construction joints are divided into 4 categories:

	k_T		μ
- smooth	0	0	0,5
- plane	1,4	0	0,6
- rough	1,8	0	0,7
- keyed	$2\text{x}n_k$	$1\text{x}n_k$	0,9

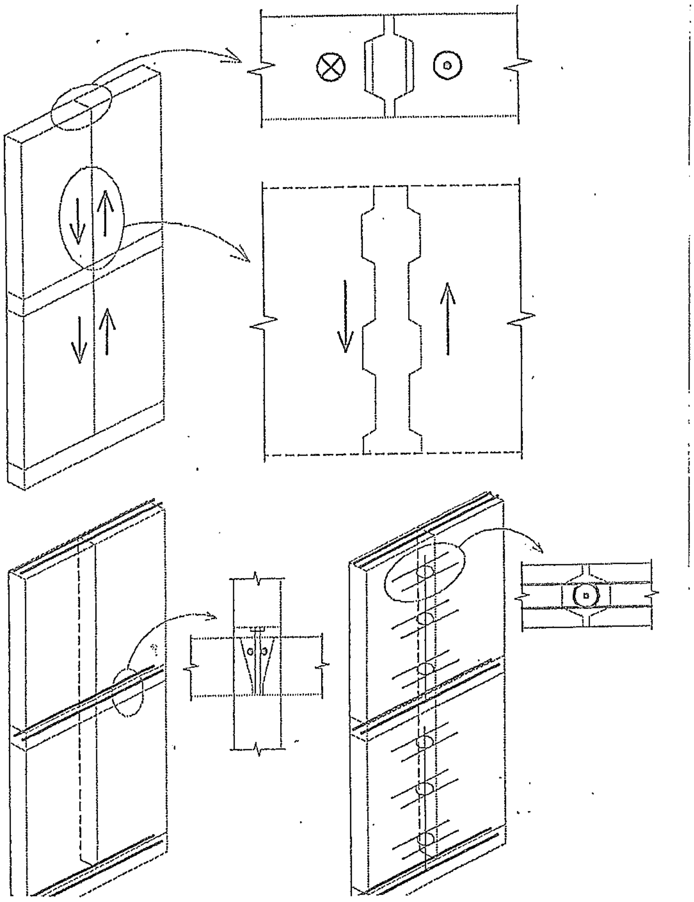
where n_k is linked to the geometry of the keys.

All catagories can be calculated in accordance with the following formula:

$$t_{shear} = k_T\text{x}t_{cd} + \mu(\rho\text{x}f_{yd}\text{x}\sin\alpha + \sigma_{nd}) + \rho\text{x}f_{yd}\text{x}\cos\alpha < 0{,}5\text{x}v_c\text{x}f_{cd}$$

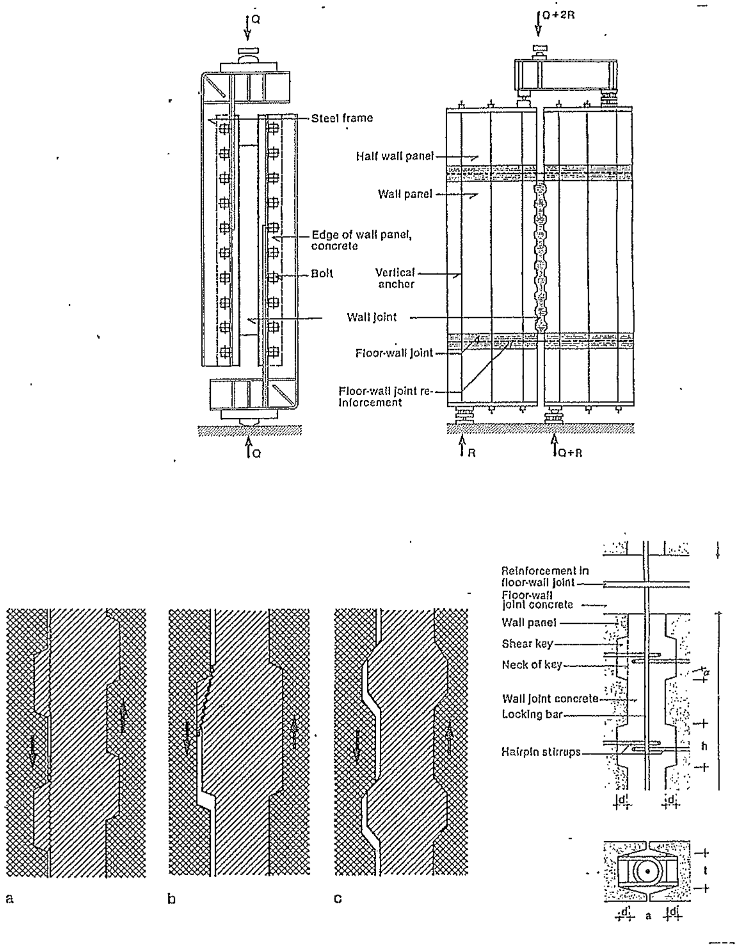


Keyed shear joint, 1

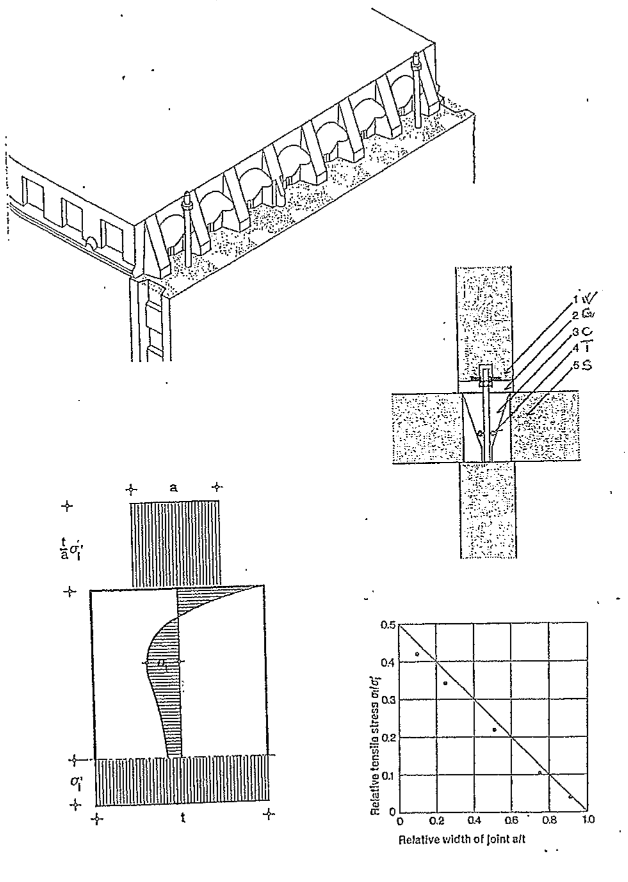


Keyed shear joint, 2

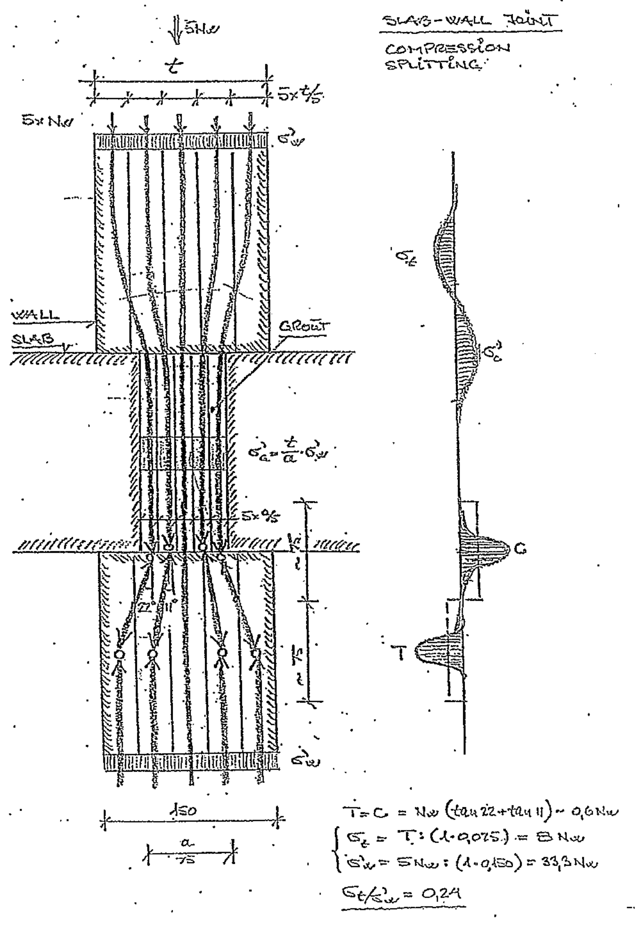
ENCLOSURE 2

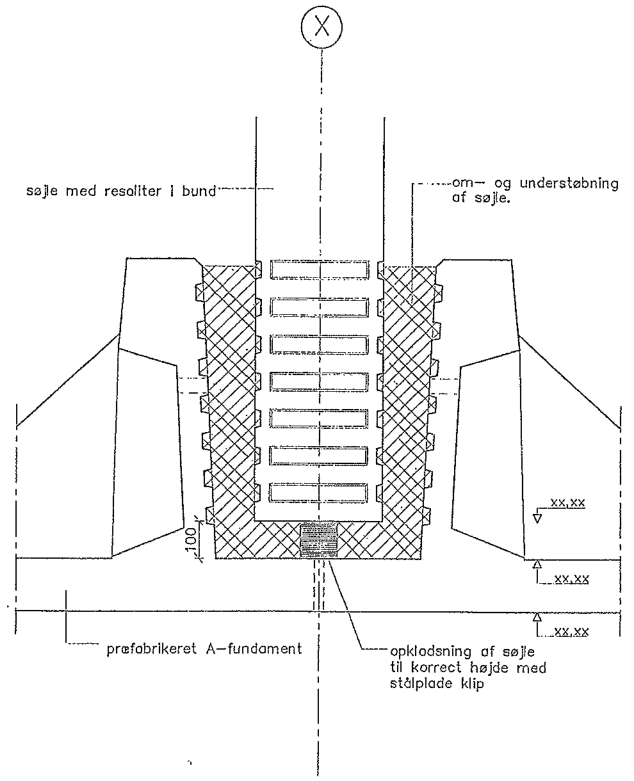


Wall-slab joint 1,- geometry and test results

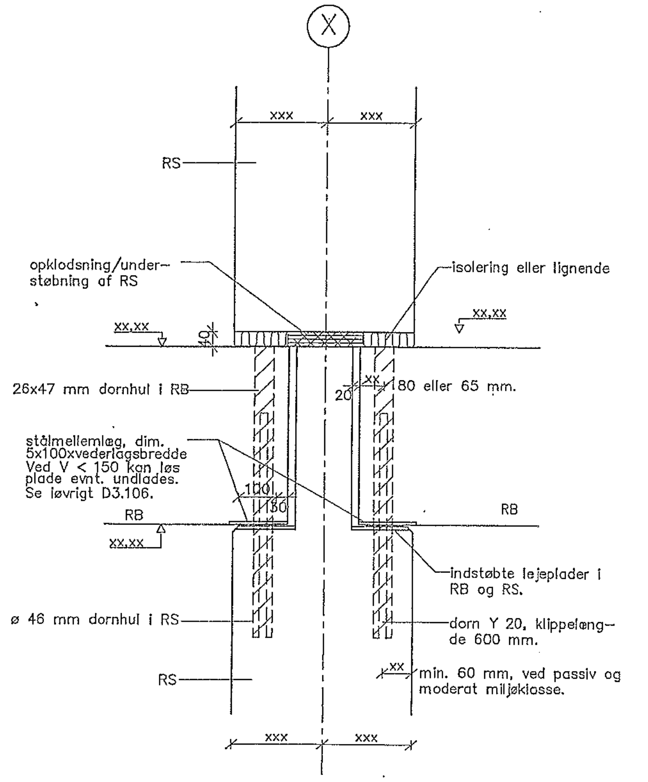


Wall-slab joint 2,- design by hand





Detailsnit RS i præfabrikeret A-fundament (indspændt søjle)



Detailsnit af samling mellem RS og RB-bjælker med dornsamling i etagekryds.

jj 05.06.07 08.40 D3-101_RS-RS--RB-RB_etagekryds.dwg

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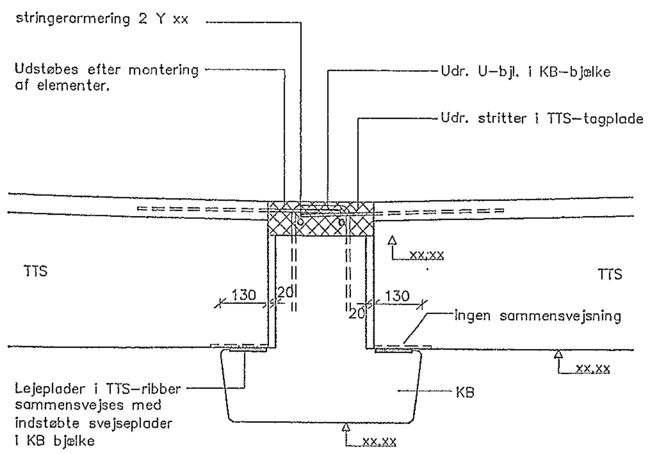
Telefon: 8888 8200
Telefax: 2817 8202



NOTE:
KB-bjælken må kun vridningsindspændes i en TTS.
Der tages hensyn til evt. vridningspåvirkning af KB-bjælken.
Endvider skal KB-bjælken sikres mod kæntring under montage.

Detailsnit af samling mellem TTS og KB-bjælker med støbt stringer

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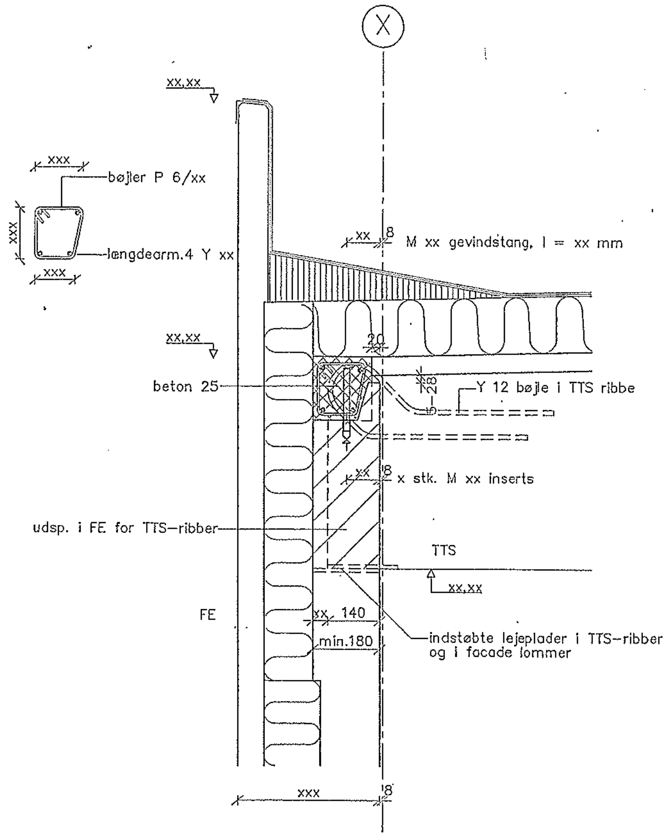
Telefax: 2817 8202



Detailsnit af samling mellem TTS-tagplader og mellemliggende VFL 480 og sandwich facader med støbt stringer.

bg 12.10.06 13.04 D1-102_TTS-FE_stobt-stringer.dwg

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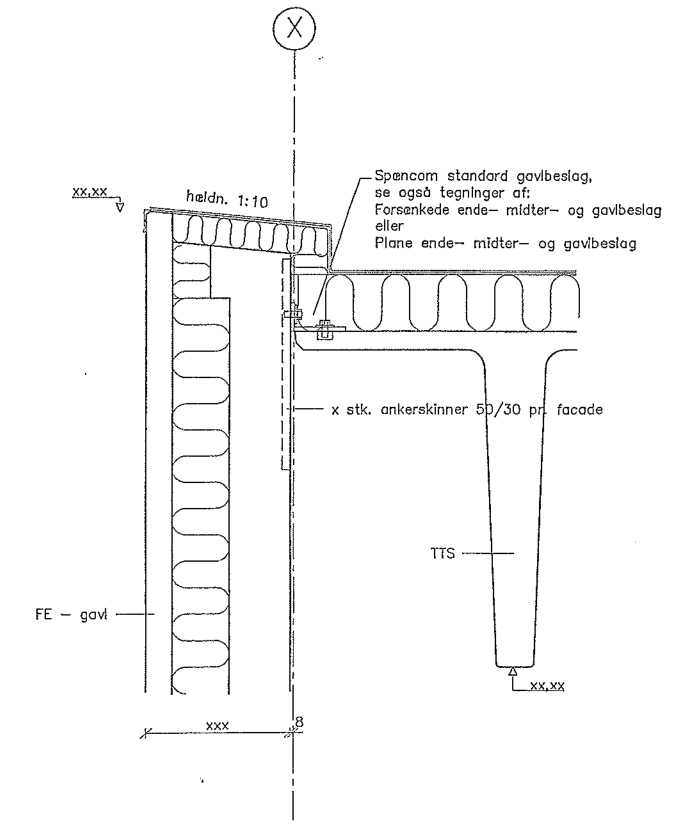
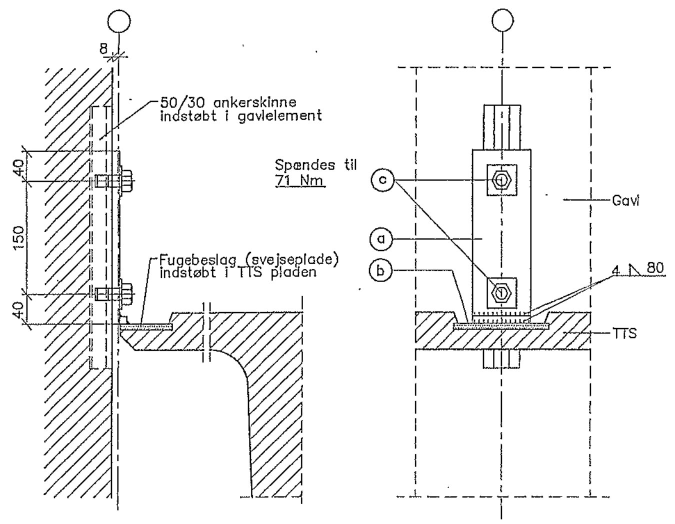


Detailsnit visende samling mellem TTS-tagplader og sandwich facader i gavl.



Snit i gavl

Opstalt

Samlingen udføres ud for midten af gavlelement (suplement til ANV 5300-1 og 5300-3.)

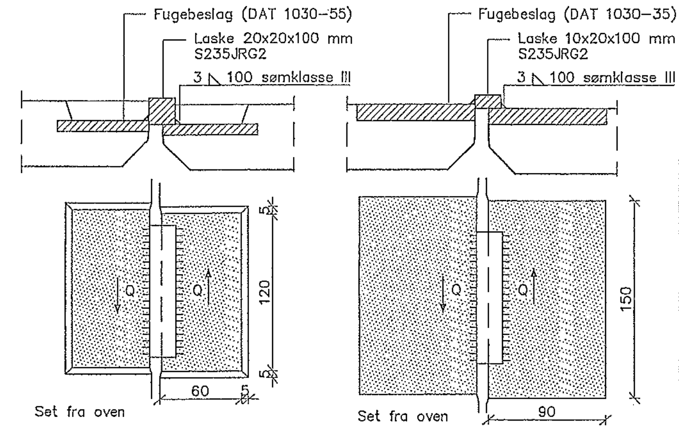
Der kan overføres en regningsmæssig forskydningskraft på
Q = 10 kN fra tagskiven til gavlelement

Pos.	Stk.	Vægt kg	Dim	Materiale	Overflade
a	1	1,44	pl. 80x10x230 med 2 ø22 huller	S235JRG2	ubehandlet
b	1	0,06	pl. 10x10x80	S235JRG2	ubehandlet
c	2	–	M20 hagebolt, L=55 med møtrik til 50/30		el-forsinket
	2	–	underlagsskiver 40x40x4		ubehandlet
Tolerancer		Ialt:	Svejsning DS 412 sømklasse III	Overflade	

ii 31.10.06 11.01 ANV_5300-03_(D1-107).dwg

Forsænket fugebeslag
anvendes også ved tætoplagte TT, uden overbeton eller med skivevirkning ≤ 15 kN.

Plant fugebeslag



Set fra oven

Set fra oven

Samlingens kapacitet sættes til 15 kN regningsmæssig, dvs. 50 % af den maximale og er fastlagt på grundlag af Fugebeslagenes bæreevne (se PRO 1030-1). Fugebeslag samles med svejsning ved hjælp af laske.

Q = 15 kN

M = 0,012·15 = 0,18 kNm

Der svejses med kantsøm 3 mm, l = 80 mm ≥ l regn. = 74,0 mm

$\tau_o = \frac{15 \cdot 10^3}{3 \cdot 74}$ = 67,6 N/mm²

$\sigma_{90} = \tau_{90} = \frac{0{,}18 \cdot 10^6}{\frac{1}{6} \cdot 3 \cdot 74^2 \cdot \sqrt{2}}$ = 46,5 N/mm²

Idet der regnes efter DS412, normal sikkerhedsklasse, normal materialekontrol, samt at svejsninger udføres i sømklasse III, haves følgende :

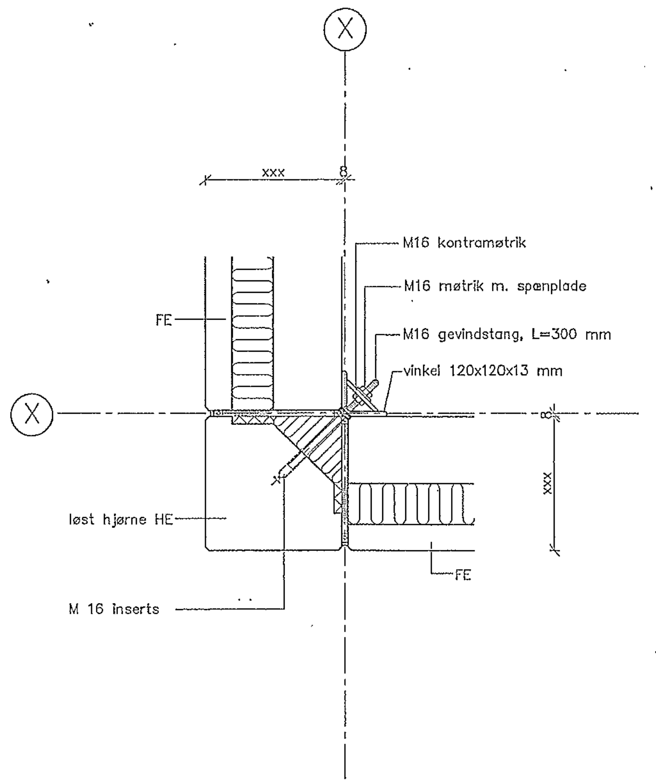
$f_{ud} = \frac{f_u}{\gamma_m} = \frac{340}{1{,}43}$ = 237,8 N/mm²

Flydebetingelsen jfr. DS412 pkt. 6.5.2 giver :

$f_{ud} \cdot \frac{c_o}{\beta_w} \geq \sqrt{\sigma_{90}^2 + 3(\tau_o^2 + \tau_{90}^2)}$

$237{,}8 \cdot \frac{0{,}7}{0{,}8} = 208{,}1 \geq \sqrt{46{,}5^2 + 3(67{,}6^2 + 46{,}5^2)}$ = 149,5 N/mm²

$c_o \cdot f_{ud} = 166{,}5 \geq \sigma_{90}$ = 46,5 N/mm²



Detailsnit af samling mellem FE og hjørne HE.

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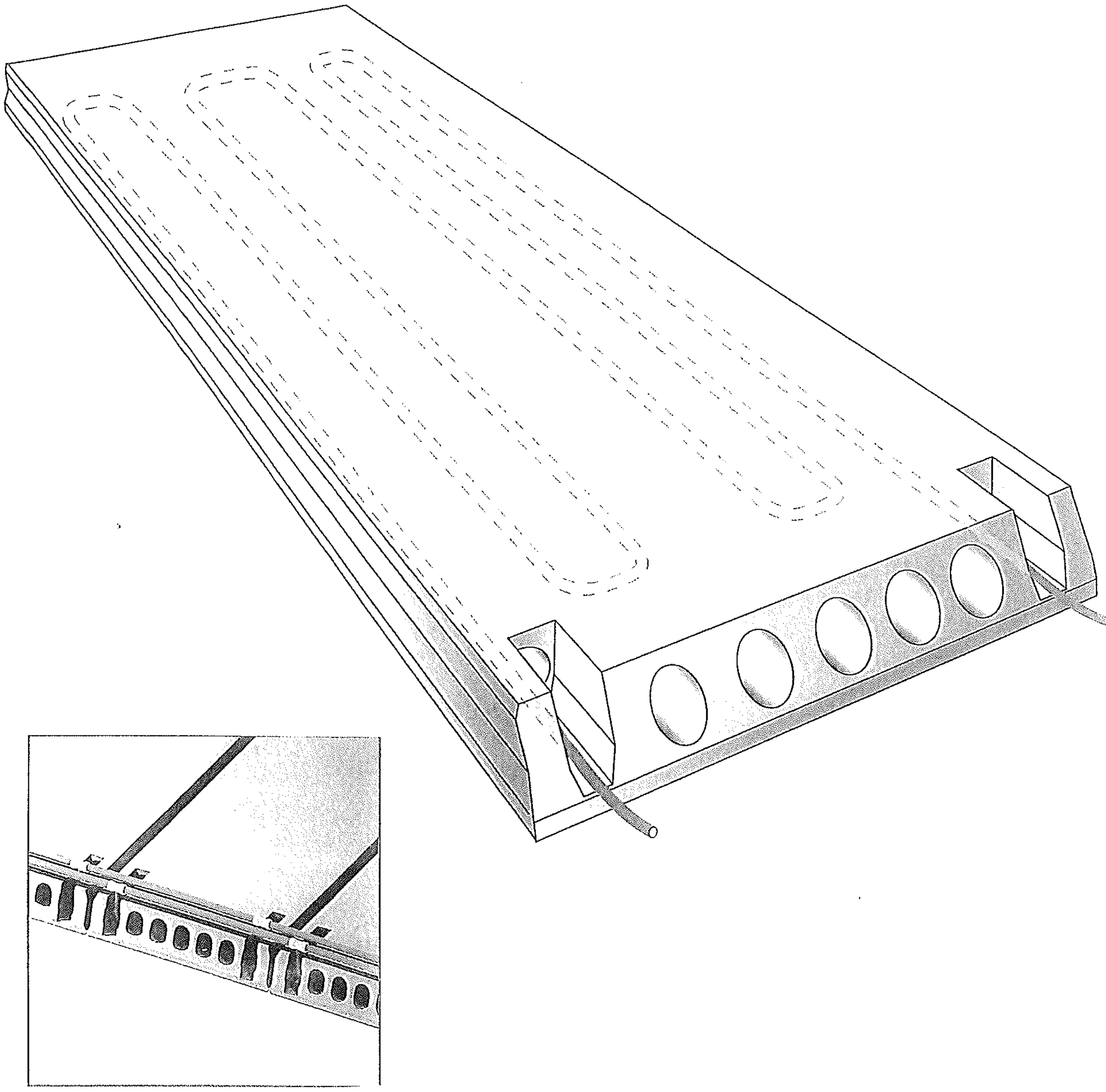
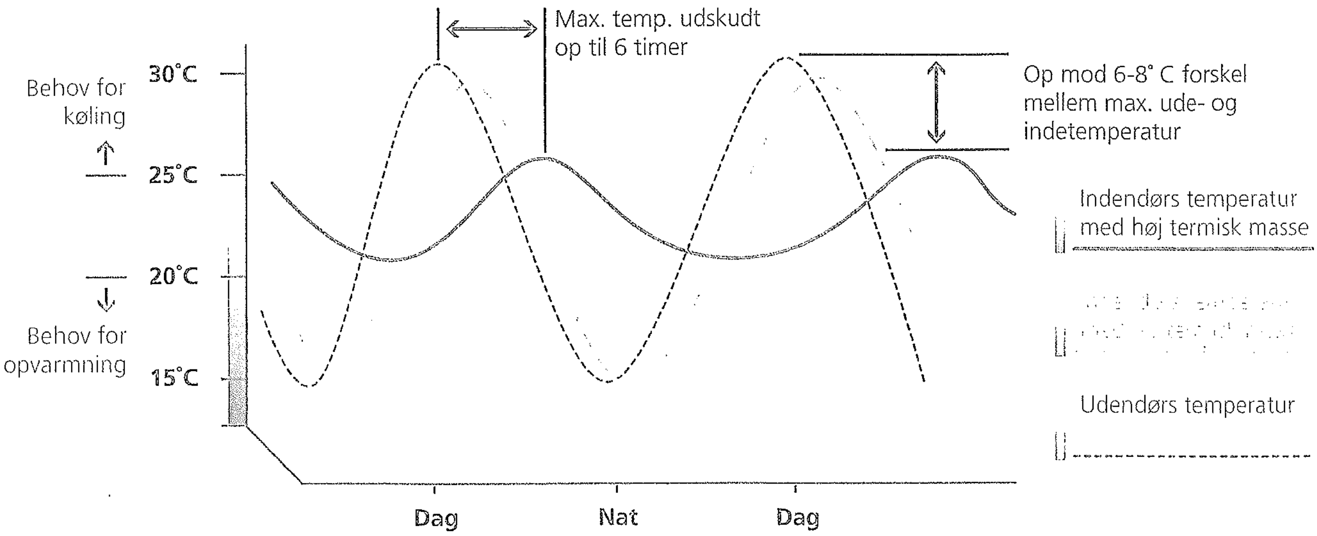
TermoMax




Max. temp. udskudt
op til 6 timer
Behov for
køling
30°C
25°C
20°C
Behov for
opvarmning
15°C
Op mod 6-8° C forskel
mellem max. ude- og
indetemperatur
Indendørs temperatur
med høj termisk masse
Udendørs temperatur
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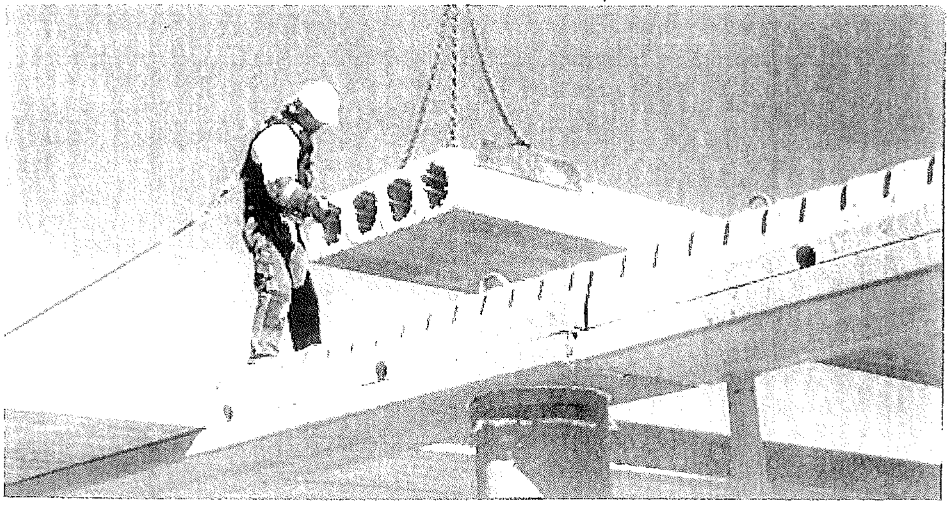
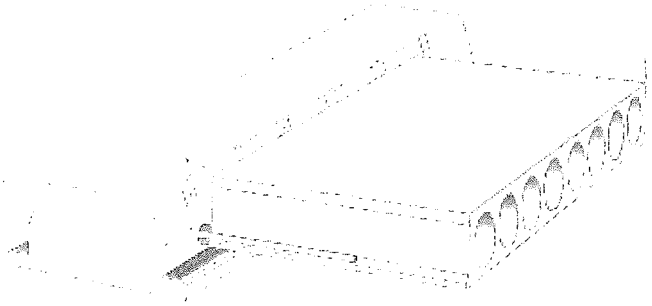
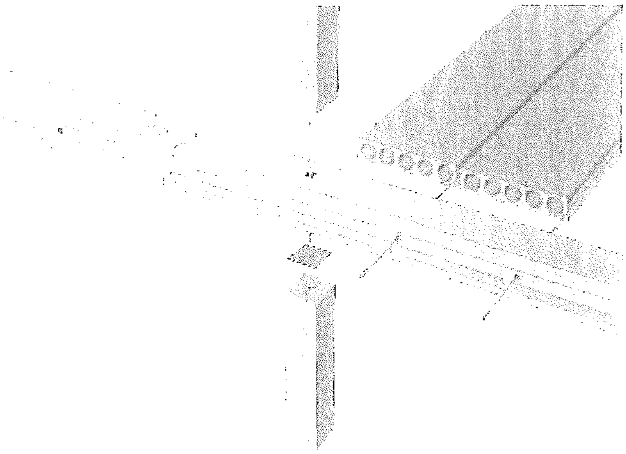
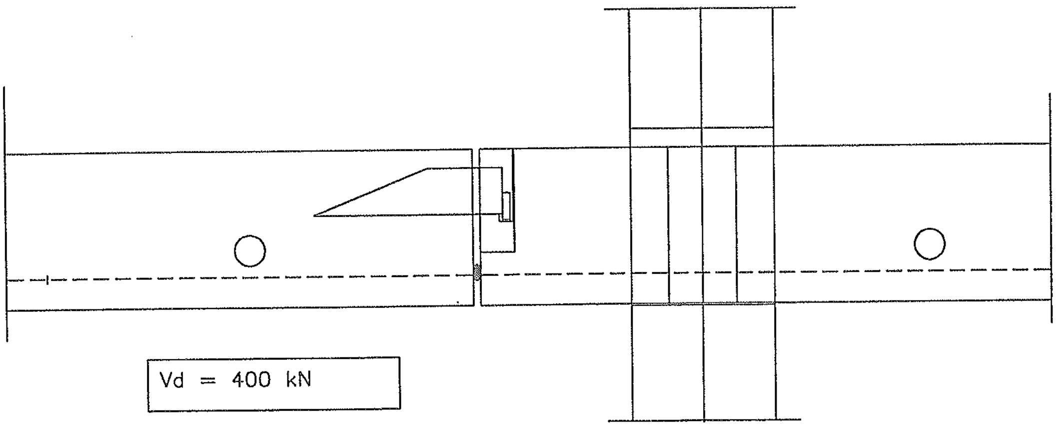


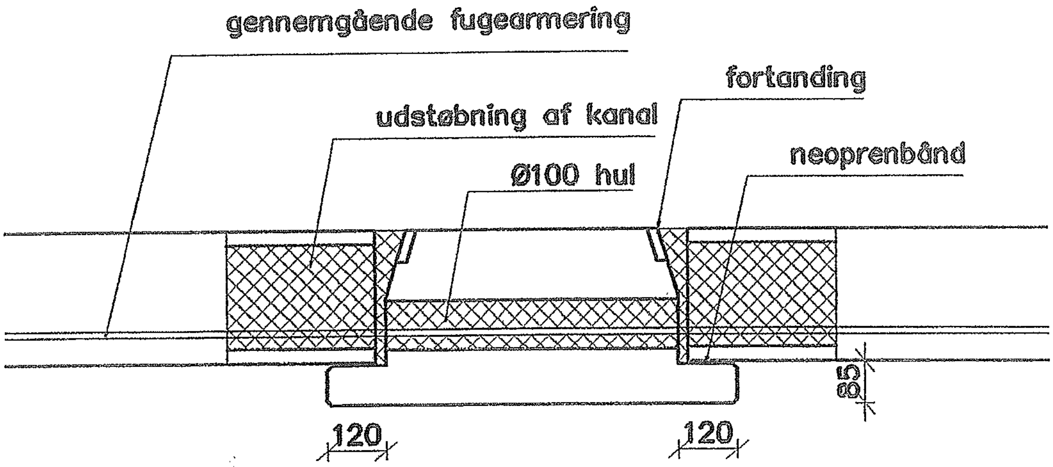




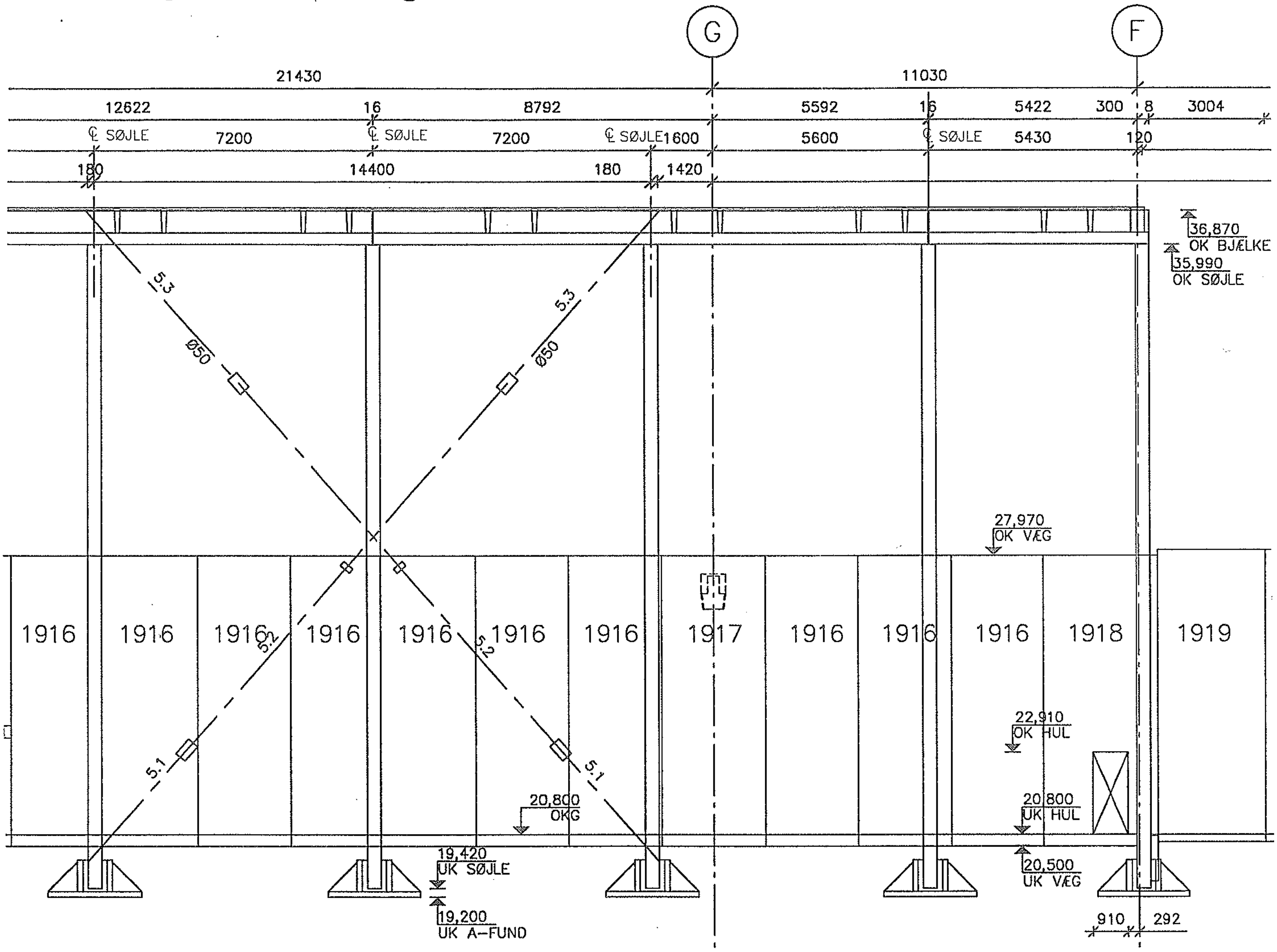
Spæncom

LB Beam - connection

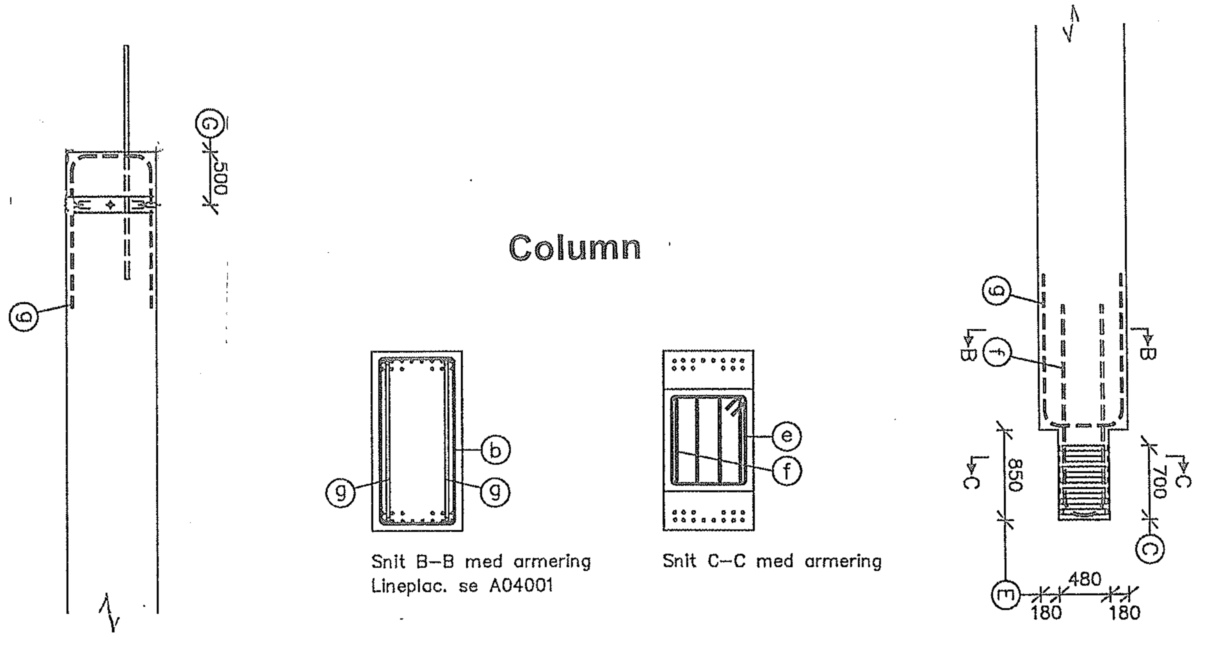


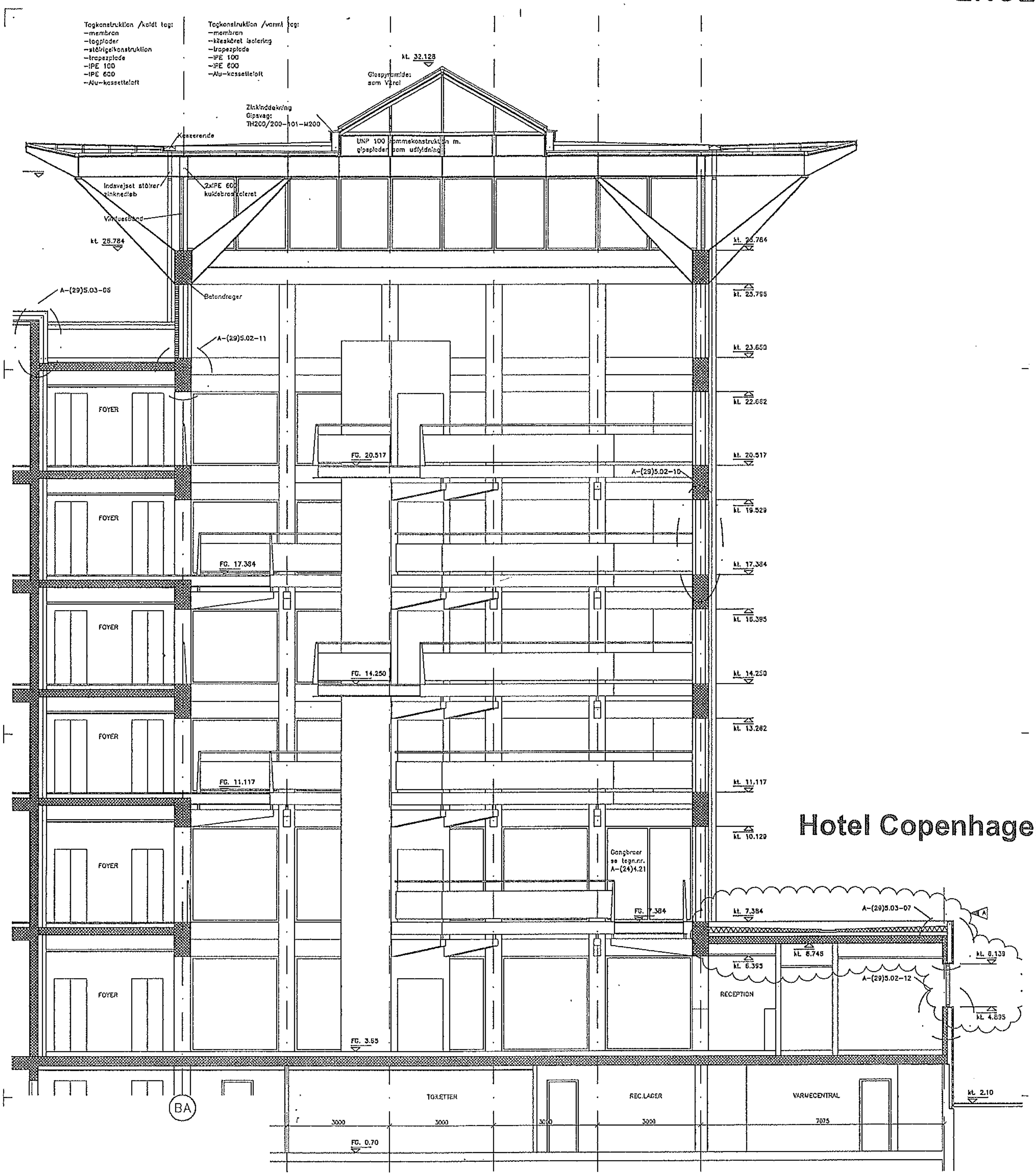


Netto-high store building



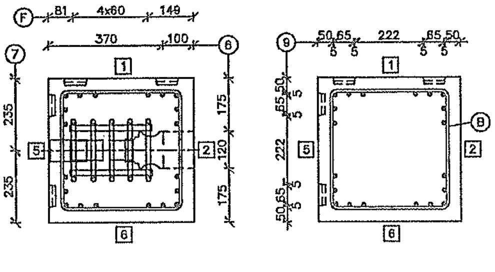
Column



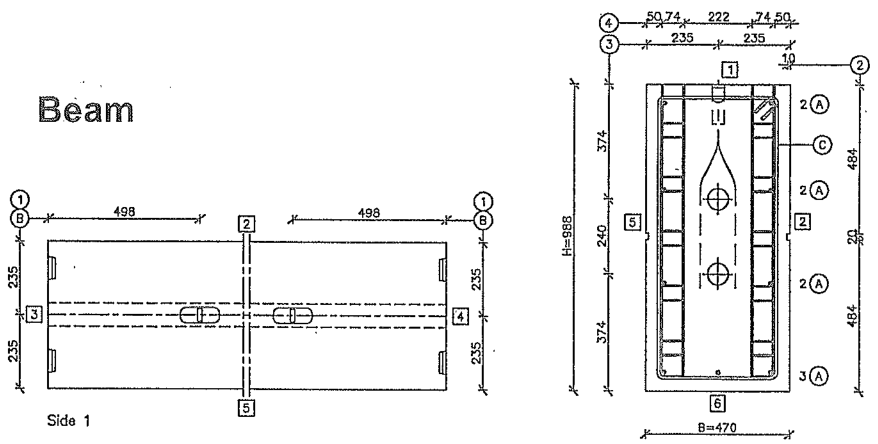


Hotel Copenhagen Island

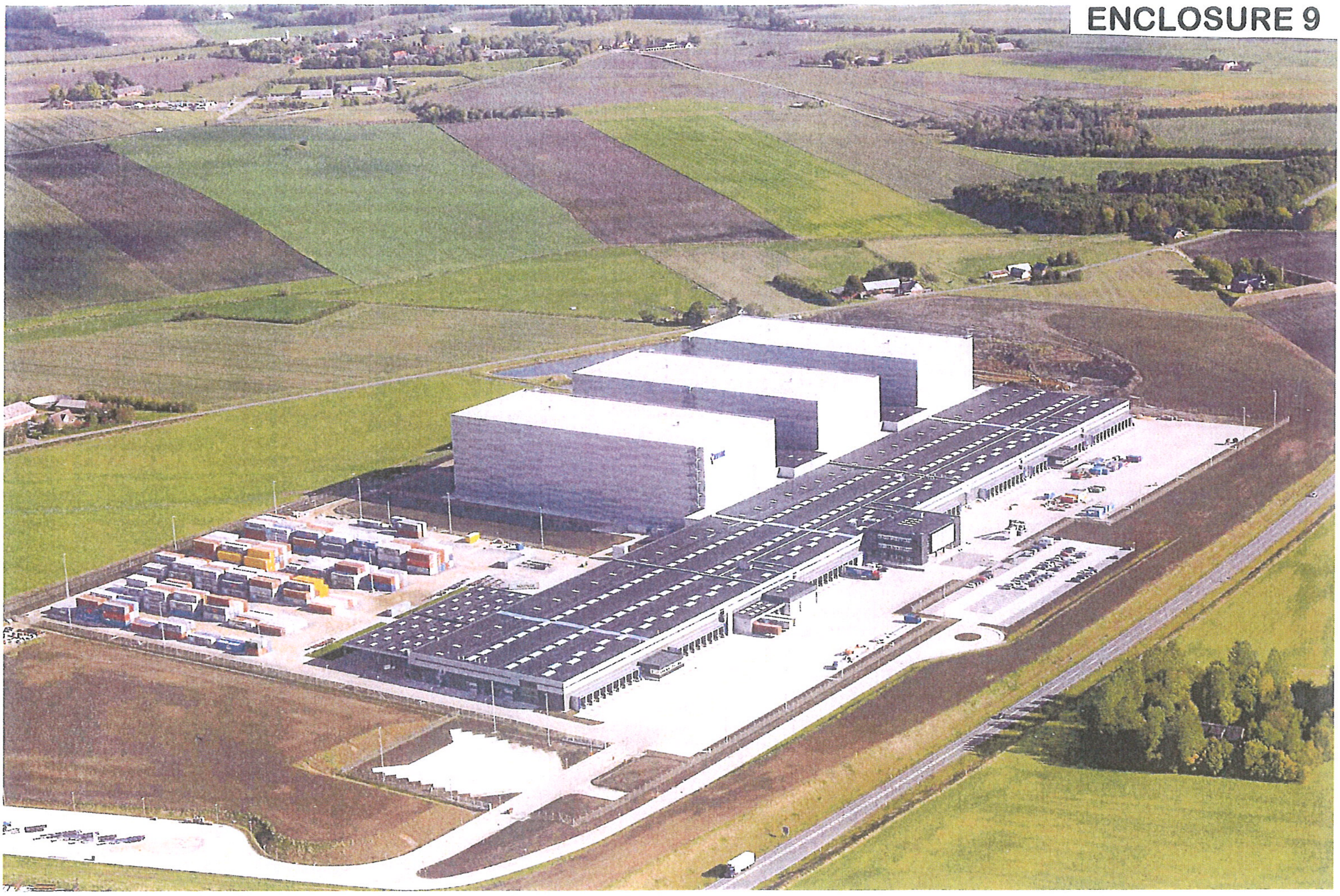
Column



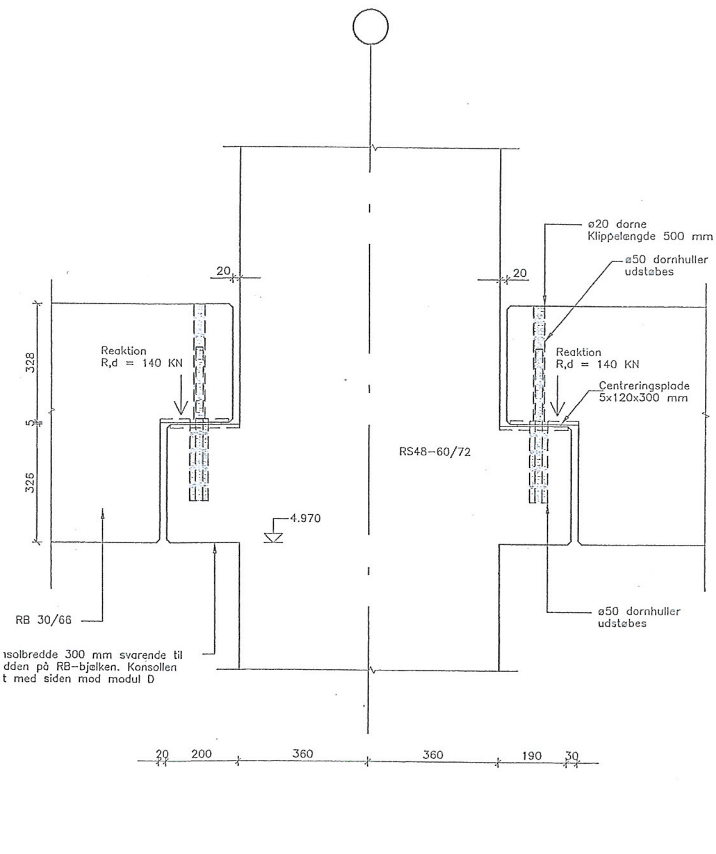
Beam



ENCLOSURE 9



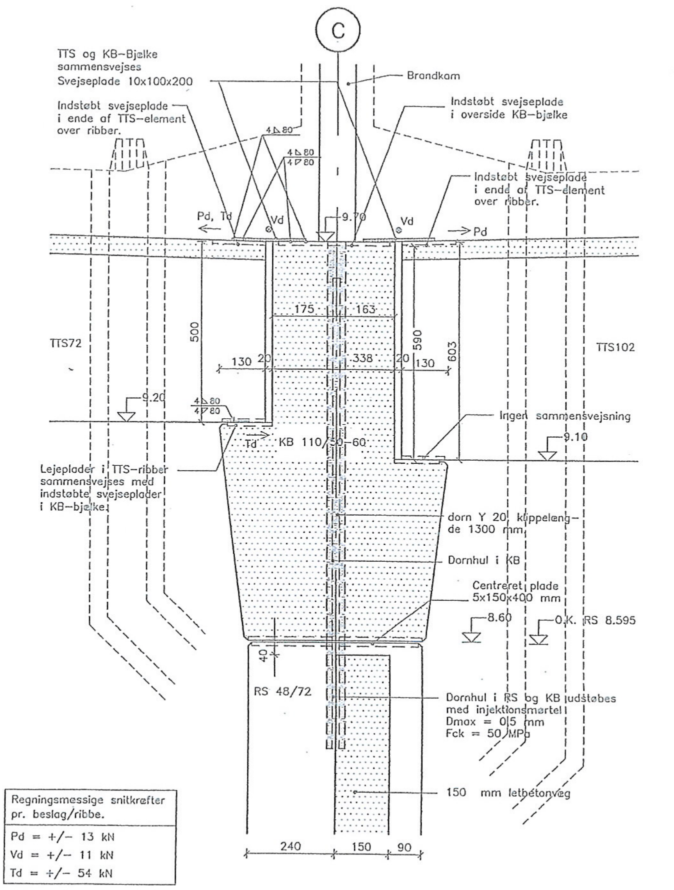
JYSK-central store building



Snit 74.12

Sag nr.: 09.065.00	Tegn. nr.: K-74	Rev.: C	Side nr.: 15

NIRAS Rådgivende ingeniører og planlæggere A/S. Banegårdspladsen 6B. 7400 Herning. Tlf. 9626 6226. Fax. 9626 6225



Regningsmessige snitkræfter pr. beslag/ribbe.
Pd = +/- 13 kN
Vd = +/- 11 kN
Td = +/- 54 kN

Bjælker svejses sammen i toppen, så bjælkerækker virker som stringer – se snit 74.58
Se detalje 74.33 for fastgørelse af letbetonvæg til KB-bjælke

Snit 74.23

Sag nr.: 09.065.00	Tegn. nr.: K-74	Rev.: F	Side nr.: 26

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ENCLOSURE 10

BYGHERRE: JYSK Holding A/S | SAG NR.: 20/06
TEGNING NR.: E1 | MÅL: 1:10 | DATO: 01.02.07

UBENÆVNTE MÅL ER I MM
KOTER ER RELATIVE

REV: 06.02.07
08.02.07
21.06.07

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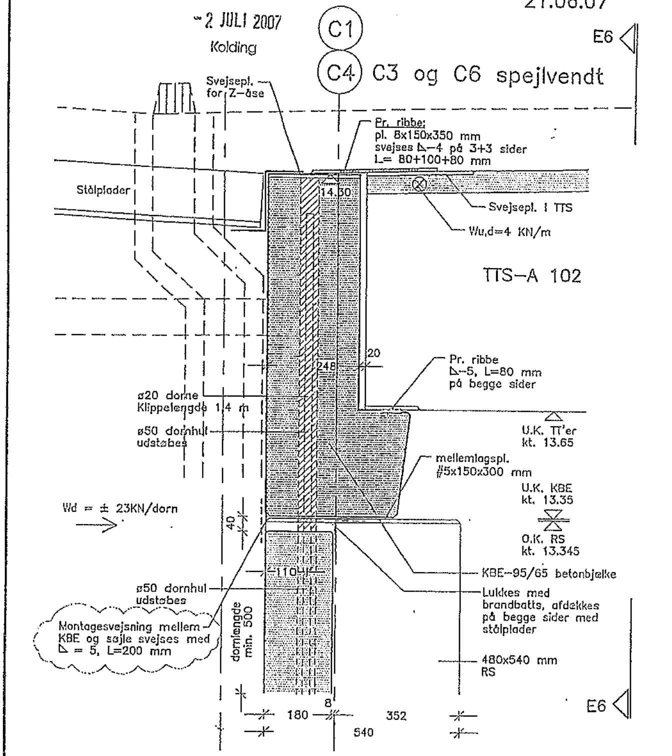
- 2 JULI 2007
Kolding



SAMLING MELLEM TTS/KBE-BJÆLKE/BS-120 VÆG
I MODUL C1+C3+C4+C6, MÅL 1:10

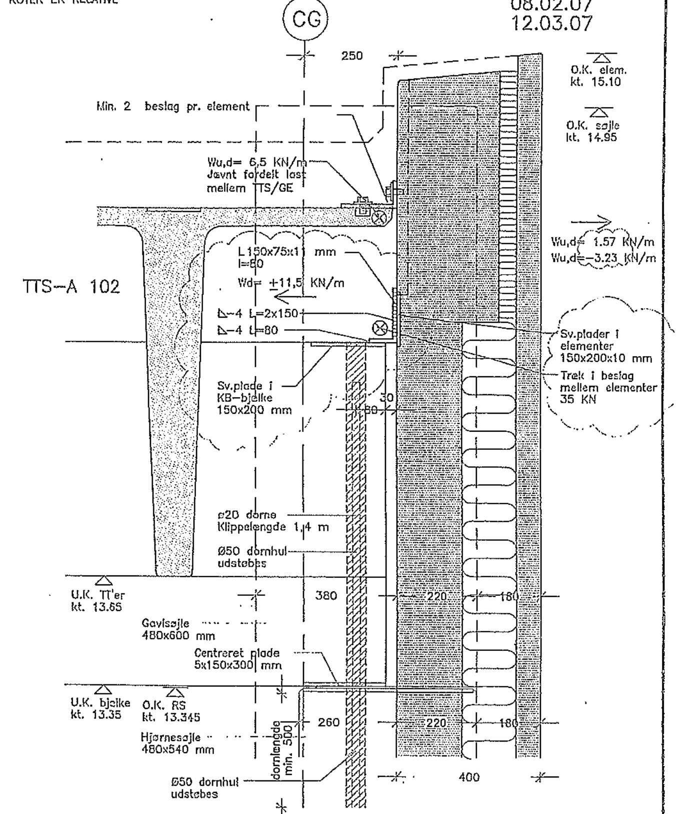
MINILOAD

OPTEGNING: MIDTJYDSK TOTALBYG A/S DALGAS PLADS 6 - DK-7400 HERNING - TLF.+(45) 97126544
BEREGNING: NIRAS BANEGÅRDSPLADSEN 6B - 7400 HERNING
Rådgivende ingeniører og planlæggere A/S Tilsluttet F.R.I Telefon 8626 6226

BYGHERRE: JYSK Holding A/S
TEGNING NR.: E4 | MÅL: 1:10

UBENÆVNTE MÅL ER I MM
KOTER ER RELATIVE

REV: 06.02.07
08.02.07
12.03.07



SAMLING VED GAVL MINILOAD MODUL CG (BS-120)
MÅL 1:10

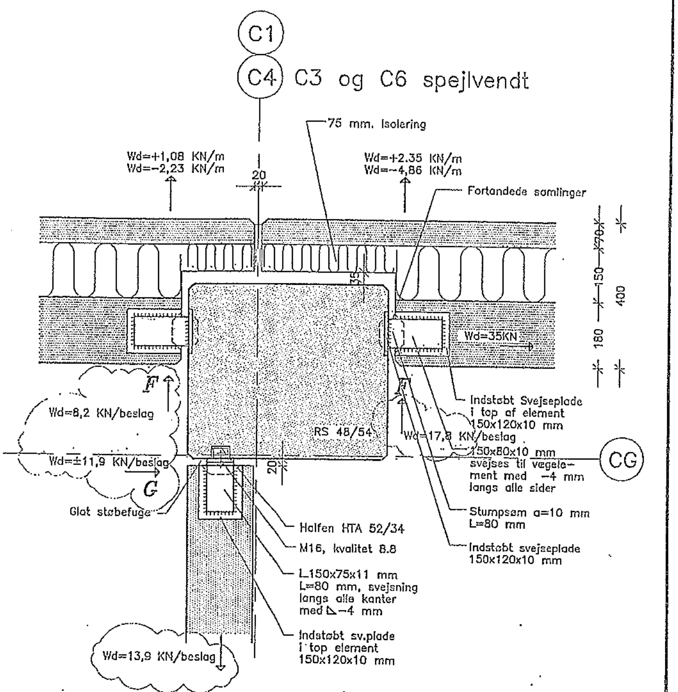
MINILOAD

OPTEGNING: MIDTJYDSK TOTALBYG A/S DALGAS PLADS 6 - DK-7400 HERNING - TLF.+(45) 97126544
BEREGNING: NIRAS BANEGÅRDSPLADSEN 6B - 7400 HERNING
Rådgivende ingeniører og planlæggere A/S Tilsluttet F.R.I Telefon 8626 6226

BYGHERRE: JYSK Holding A/S | SAG NR.: 20/06
TEGNING NR.: E12.1 | MÅL: 1:10 | DATO: 01.02.07

UBENÆVNTE MÅL ER I MM
KOTER ER RELATIVE

REV: 08.02.07
12.03.07



NB:
Vedr. samlinger Se opstalt tegn. nr. 200

SAMLING, HJØRNE RS 48/54-FE 40 CM. (BS-120),
MINILOAD MODUL CG, MÅL 1:10

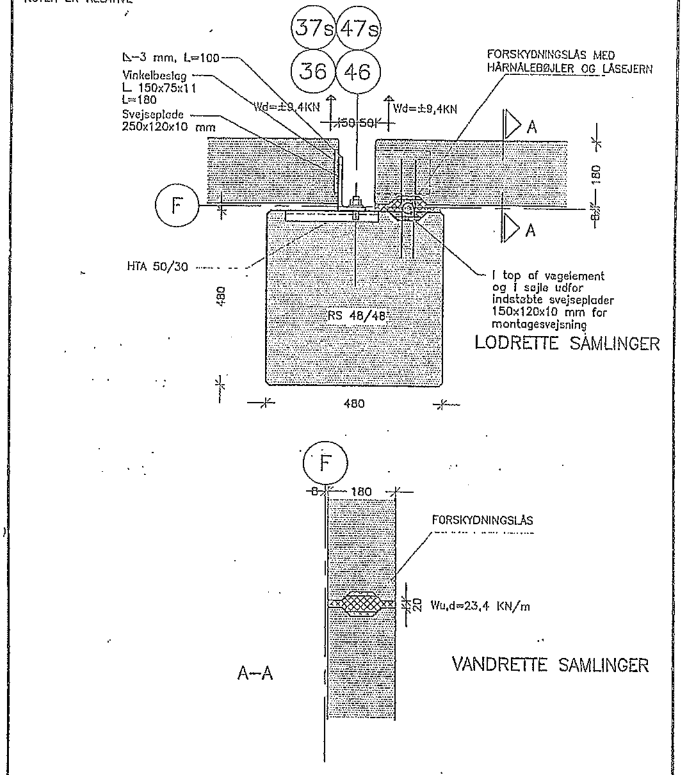
MINILOAD

OPTEGNING: MIDTJYDSK TOTALBYG A/S DALGAS PLADS 6 - DK-7400 HERNING - TLF.+(45) 97126544
BEREGNING: NIRAS BANEGÅRDSPLADSEN 6B - 7400 HERNING
Rådgivende ingeniører og planlæggere A/S Tilsluttet F.R.I Telefon 8626 6226

BYGHERRE: JYSK Holding A/S | SAG NR.: 20/06
TEGNING NR.: E15 | MÅL: 1:10 | DATO: 01.02.07

UBENÆVNTE MÅL ER I MM
KOTER ER RELATIVE

REV: 13.02.07



SAMLING RS/BRANDVÆG I MODUL F
MÅL 1:10

MODUL F

OPTEGNING: MIDTJYDSK TOTALBYG A/S DALGAS PLADS 6 - DK-7400 HERNING - TLF.+(45) 97126544
BEREGNING: NIRAS BANEGÅRDSPLADSEN 6B - 7400 HERNING
Rådgivende ingeniører og planlæggere A/S Tilsluttet F.R.I